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ABSTRACT

Examples of explanations students give during science lessons are used to demonstrate that there are a number of very different modes of explaining. In addition, it is suggested that the peculiarly scientific method of explanation is fraught with difficulties, some of which current learning theories may just be able to describe. Areas discussed include: (1) questions children ask which are primarily not requests for reasons but requests for reassurance; (2) explaining a meaning by replacing one word with a simpler one with the same meaning; and (3) the use of metaphors and similes. The examples are also used to illustrate some stages in the developing art of explanation. However, no claim is made either that suggested demarcations are sharp or that the stages are strictly developmental. Reaffirming that things are as they are, looking for the purpose of events, trying to find life-world synonyms for concepts, close comparison, seeking causes, and using distanced analogies can easily merge each other; furthermore, the different ways of explaining may continue to be used in some contexts long after the more sophisticated methods have, apparently, been mastered. (JN)

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CHILDREN'S EXPLANATIONS

Joan Solomon.

It is the business of science to explain, as best it can, all the happenings of the natural world; indeed Einstein once called scientists people "with a passion to explain". Asking questions also comes very naturally to our young children; words like "what?", "why?" and "how?" are much used by them and the answers they receive then teaches them about the nature of explanation.

This paper will use the explanations given in science lessons by high school students to demonstrate that there are a number of very different modes of explanation. It will suggest that the peculiarly scientific method of explanation is fraught with difficulties, some of which current learning theories may just be able to describe.

Things as they are.

Most of the questions our youngest children ask are not so much a request for reasons as for reassurance. When something new and startling occurs they ask hoping to hear that all is well. Any similarity with the scientist's urge to accommodate new and disconcerting anomalies into established theory is probably more apparent than real. The children seek not so much a reason as a simple redescription which emphasises its normality. Their parents either anticipate this need, or perhaps reinforce it, by their answers.

"Why have all the lights gone out?"
"Because we are having a blackout."

"Why does that man have such a long nose?"
"He was just born like that."

Explanation need not imply causal links.

It was through Piaget's early recording of children's talk that their ways of explaining were first examined. In 1926 he drew attention to three important characteristics; to a certain **realism** which holds close to nature as it is known, to **finalism** which explains through naming the purposes of happenings, and to a kind of phsychological **reaffirmation** which may give some reassurance.

> "..The child reasons, as he draws, according to a kind of "internal model", similar to nature, but reconstructed by his intelligence,... everything in it can be explained psychologically....Thus the child invokes as causes sometimes motives or intentions(finalism), sometimes pseudo-logical reasons which are of the nature of a sort of ethical necessity hanging over everything("it always must be so")."

(Piaget 1926)

In a later book (Piaget 1928) he showed that "why?" questions were rarely answered by the empirical "because" and even less often by logical justification. Instead assertions or descriptions were simply **juxtaposed** in a way which convinced Piaget that these children (aged between 5 and 8) were unable to comprehend the nature of explanation. "....a confusion of physical causality with psychological or logical motivation. Hence, once again, precausality."

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It is not necessary to agree that these ways of thinking are so strictly age-related. Of its early appearance one could agree both that more elaborate causal and logical thinking is unlikely, and that parental reassurance might well have reinforced it. Rules, for example, are always explained in a finalistic or teleological way. Even when the child has acquired more analytical methods of explaining, early modes remain entirely appropriate for many contexts, including some in Biological science. Teleological reasoning, although acausal, cannot be dismissed as mere juxtaposition: it constructs links between a local event and its purpose in another domain.

After school science teaching has begun, both these acausal methods of explanation linger on. Few teachers give explicit instructions on how scientific questions should be answered so students learn from their own mistakes. The following list of examples indicates how imperceptably the impoverished approach of reaffirmation slides into more reflective thought about the purpose of items or happenings.

Q."Gold can be found as the pure metal in the earth's crust.Iron cannot be found as a pure metal. Why is this?"
A. "Because iron is not found in the earth's crust." Grade 7

Q."Use the idea of gravity to explain why neither the moon nor the small planet Mercury have any atmosphere, but the more massive planets do."
A."..because it does not need an atmosphere because it is so small."Grade 8.

Q."Why does the vibrating arm on the timer move up and down?"
A." So that the experiment will work." Grade 8.

Q. "Why does the drop of water move down the tube when the insect breathes?"
A. "In order to give it more air." Grade 7.

Explaining the meaning

Another mode of explanation that young children learn early is that replacing one word by a simpler one with the same meaning constitutes a useful clarification. If their problem is an inadequate vocabulary then what is required is a more familiar synonym. The success of this kind of response encourages the answering of questions in a semantic rather than an analytical sense. Once again the difficulty for children is that an appropriate response in one context,"What is circumlocution?" is not appropriate for another,"What is energy?".

In a simple test four classes of grade 6 students were asked, during their science lessons, to explain what the word energy meant. None of them had yet studied a formal course on energy. Figure 1 shows the "meaning structure" (Schutz and Luckmann 1973) of words given by those students who had answered simply "it means..." or "it is...". Some used two words, such as "strength and power", or "being fit and running about". From such composite answers it was possible to allot neighbouring positions to some of the words used: they also suggested that these were further examples of simple juxtaposition of semantically adjacent meanings.

Of the 93 children in the sample, 10 made an attempt to explain energy by a more reflective method which involved synthesising a meaning out of different notions or events. These answers ranged from

"it is a source of force", to
"it is an invisible power which makes everything move.",

and

"it powers us and machines."

Separating explanations which are semantic juxtaposition from those which evoke notions from another domain may not be easy. Consider the question

"Name 4 methods of preserving foods for long periods. For each method describe why it works."

Several grade 9 pupils, after giving their example, wrote that it preserved foods "because it protects them from going bad", or "keeps them fresh". Such phrases seem to be offered as simple synonyms for preservation: no attempt was made to connect the word with taught ideas about bacterial action. The jump to such a distant explanatory domain is often difficult, especially when the contiguous life-world meanings are available (Solomon 1983). One pupil, after giving addition of vinegar as the method, wrote "it pickles them". Does pickle mean no more than protect by adding vinegar, or was the pupil referring to other pickling liquids? Lack of precision in life-world usage conceals and protects its structures. In the words of Stephen Pepper(1942) they are "cognitively irritable".

It is possible to find the same mode of explanation, descriptive and reiterative rather than causal, without the use of words. Two grade 8 classes who were studying a preliminary course on light were asked to draw a <u>diagram</u> to explain why the shadow of a person was longer in the evening than at midday, and to include the position of the sun. Then, one week later, the same students were asked to explain <u>in writing</u> what a shadow was.

Some students failed to make any causal links; they drew a shadow, but it was unrelated to the sun's position (Figure 2 shows some of the drawings which fell into this category.) In the written test there were those who could only explain by using near synonyms - "image", "black shape", or "reflection".The more successful students drew in the shadow so that the sun's position explained its size and direction (Fig 3). In the written papers answers such as "the shadow is where the light of the sun is blocked out" were equally causal and successful.

There were 41 students in the group; five of their papers proved too difficult either to read or to categorise. The remaining 36 pairs showed a significantly high association between showing cause of the shadow by diagram and by words.

$Q=0.81 \pm 0.14$

These data suggest that the capacity to explain by using a feature at some remove from the phenomenon, such as the position of the sun, rather than just to describe the phenomenon is <u>not</u> an exclusively linguistic effect.

<u>Metaphors and similes.</u>

One way to construct an explanation which spans some mental

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distance is to make a comparison with a different phenomenon in order to explain a feature of the event. Sometimes when students struggle to explain an idea the words they choose do give the impression that another domain of experience is being used in an imaginative way. Many scientists have reported that some such process has guided their thoughts during especially successful and innovative phases of research. This suggests that the metaphorical language of students deserves much more exploration than it has received so far in science education.

The subject is not easy. It is hard even to be sure from the words used that a metaphor is intended. Consider the following examples:-

"If a car is aerodynamic it just slices through the air, whereas a Land Rover pushes through the air." Grade 7

"More massive planets have an atmosphere because the massive planets have such strong gravity that it creates a barrier to space and so you get air and such like."Grade 8

"A shadow is when an object is close to a light and casts a dark light."Grade 8.

Common metaphorical usage is a very mixed blessing in science lessons for reasons which have been examined elsewhere (Solomon 1984). In the present context the problem is that a very large part of the lexicon of current vocabulary has derived from metaphor. In their time "harnessing energy" and " alling in love" may have been striking metaphors using images from one domain (the dray horse) to illuminate another (technology). Now metaphorically dead they are no more than the appropriate word for the occasion.

> "It is indisputable that figurative language is one of the most productive sources of linguistic change. It is commonplace that most lexical items prove to be dead metaphors which were alive and kicking at some time in the past."(Sadock 1979)

Words whose metahorical power is not yet quite dead are troublesome to interpret. "Slicing through the air" is effective although no longer pristine, while " a barrier to understanding" is moribund enough to evoke almost no visual image in the listener, and a barrier to gravity might be much the same. In such cases any distance between the terms within the explanation, which true comparison might have provided, is lost: the explanation is on the road to relapsing into trite reaffirmation. (The reader is left to decide whether the third example constitutes a fresh and useful metaphor, literal but inexact science, or an unconscience reference to the famous Pauline image in Corinthians.)

Similes are preserved from too ready an absorption into normal usage by the explicit use of "like". Nevertheless there are at least two different classes of similes - one providing direct comparison - "his nose was like a red cherry" -to the more distanced kind where an intermediate concept must be evoked by the listener if any useful sense can be extracted from the simile. This distanced simile is of particular interest here both

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because of the difficulty students find in distanced explanation, and because it relates to a peculiarly scientific method of explanation.

In a recent piece of research (Solomon et al 1985) 117 Grade 6 students and 135 Grade 8 students, drawn from four different British schools, were encouraged to use simile to show how they imagined electricity. The questionnaire offered the similes; the children were asked to indicate if they agreed or not, and then to give their reason.

"Electricity is like fire."
"Electricity is like a river"
"Electricity is like a dangerous animal"
"Electricity is like fuel, like gas or coal."

What must concern us here is not so much the verdicts of the children, as the difficulty so many of them experienced in giving a reason which maintained the function of the simile. Many who answered "no" to the first one said that you couldn't burn electricity. In the second example an even larger number said that electicity could not be like a river because it would be dangerous to have water near electricity. The fuel simile elicted answers like "electricity is a fuel", or "you can get electricity from coal". By contrast the success rate on the dangerous animal simile was high: students had no trouble in selecting the quality "danger" as the item for comparison. (Table 1)

The Grade 6 students had not yet studied electricity at school. Discerning science educators will have guessed that the point of the second simile was to find out, by a rather circuitous route, whether these young students, thought of electricity as a flowing entity. Many students did indeed respond by saying that they agreed with the simile because electricity flowed (and so does a river). In doing this they had managed to match electricity to a river by means of a quality (abiltiy to flow) which had not been given. It was a controlled distanced comparison. Even answers that rivers were wet while electricity was not, were scored as correct. The large numbers of students who produced ineffective juxtaposition instead of comparison came as a surprise to us all.

Perhaps it would have been less of a surprise had we consulted the literature on children's use of figurature language. Despite the charming and imaginative writing young children can produce it has been reported (Gardner et al 1978) that below the age of 12 very few could handle the simile "the prison guard was like a stone" although even seven year olds had no trouble with "her hair was like spaghetti". A visual image, designed for straight comparison, provides its own guide for the user; no uncharted exploration is required.

Theoretical explanation in science.

So far we have looked for empirical explanation in school science; for what Aristotle labelled the "efficient cause" for a happening. It has not been shown however that this kind of explanation, useful though it may be in a school experimental situation, is essentially scientific. Finding out what causes an engine to misfire, or tracing the fault in a program, requires insight but constitutes "trouble shooting" rather than theoretical explanation. In a perceptive essay on causation Max

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Black defined it as control or modification of events. He wrote "The vocabulary of causation can be adapted to a scientific context but the sophistication it suffers proves ultimately fatal. Scientific insight is the death of causal inquiry."(Black 1962)

Piston movement, for example, is "caused" by expanding gas; kinetic theory then submerges such simple causation by its wealth of analogical detail.

It has been argued by a number of writers that explaining by model or analogy is the peculiarly scientific method. Both are, in some sense, just more elaborate versions of metaphor. Hesse, for example, calls scientific explanation "metaphorical redescription"(1966). Such a view of theories-as-metaphors leads her to assert that if the metaphors and their deductive consequencies prove valuable they can even correct or replace the original literal description of the phenomenon.

Richard Boyd, in his essay on Metaphor and Theory Change(1979), makes a point about the use of metaphor in scientific theory which mirrors some of the observations made earlier on students' efforts to use simile. He suggests that there are two substantially different types of scientific metaphor. The first is exegetical or pedagogical, terms like "electron cloud" or "black hole", which are descriptive rather than insightful in any theoretical sense. The other type, like the atom-as-solar-system,

> "....play a role in the development and articulation of theories in relatively mature science. Their function is a sort of catachresis - that is, they are used to introduce theoretical terminology where none previously existed."

Boyd points to terms like "information processing" and "feedback" as just such theory-constitutive metaphors, imported from the domain of computers into that of cognitive psychology, because no other suitable words existed. Despite a certain vagueness in application they do more than describe; they impose a mechanism, complete with causal interpretations, upon the events.

For Rom Harre(1983) there are no less than three different kinds of analogy or model needed to describe the genesis of a scientific theory. One, the "source metaphor", provides a general way of dealing with the phenomenon; another enables useful analysis and categorisation to take place; and the third calls to mind a mechanism which, in its new context, is so close a simulation as to suggest effects and causes.

It would be possible to multiply many times the references to philosophers of science who have written about the use of analogy or models in theory building. What must concern us most is how pupils manage to understand and use these crucial theoretical analogies. In the previous section it was shown that some have difficulty in using simile when it is not simply descriptive. Theory-constitutive metaphor is often peculiarly puzzling because, as both Boyd (op. cit.) and Gentner and Gentner (1983) observe, its operation is incomplete, being paradoxically both rule-governed and yet imprecise. (The kinetic theory of gases, for example, is firmed out with rules or "assumptions" about how it is to be used, and yet it offers no guidance on hosts of other

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possible analogies like the "noise" of collision or the "colour" of the molecules). Such reflections would not lead us to anticipate any great success for our struggling science students.

There is no lack of research on school children's understanding of the kinetic theory. From that of Nussbaum and Novick(1982) to the report of CLISP (Brook et al 1983) it is clear that very many students who have been taught the kinetic theory of gases and are even reminded again of its main assumptions still cannot apply it to simple situations. Reading their verbal answers or examining the pictures they draw reveals the same story. Many students can apply the metaphor in a simple comparative way - matter is like a collection of small particles, gases are made up of millions of tiny moving balls - and yet the metaphors fail to be theory-constitutive. When the substance gets hot the particles too get hot: if the gas expands then the molecules must also have got bigger.

There is a piece of research into the teaching of electricity which is particularly instructive for the present purpose. It concerns the use of the analogy which compares elecric current to the flow of water in a pipe. Strictly speaking this is not so much an analogy of science as one of pedagogy in science, but there can be no doubt that it is, in the sense used by Boyd, theory-constitutive. Properly employed it will enable students to predict the current in parallel arms of a circuit and also the resistance in many different configurations. Tenney and Gentner (1984) showed that novice college students do not readily use this analogy. Even when a course unit on water circuits was taught immediately before a preliminary one on electric circuits, it had no significant effect on students' understanding of current unless they were specifically told to use the flow of water as an analogy. It would appear from this that explaining by means of analogy, common and obvious as it may seem does not come naturally to most students.

The cognitive problems of explanation

This paper has sketched some stages in the developing art of explanation. No claim, however, has been made either that the demarcations are sharp or that the stages are strictly developmental. Reaffirming that things are as they, looking for the purpose of events, trying to find life-world synonyms for concepts, close comparison, seeking causes, and using distanced analogies can easily merge into each other. Furthermore the different ways of explaining may continue to be used in some contexts long after the more sophisticated methods have, apparently, been mastered.

Such disclaimers cannot absolve us from examining the mental hurdles which make one method so much less accessible than another. Piaget's theory of "equilibrium" gives its well known account of how the child progresses from one stage to the next. It is possible and interesting to compare the final level of formal thought with the use of distanced analogy which as outlined here. According to Inhelder and Piaget (1958) formal reasoning involves a hypothetico-deductive method in which reality is compared with some imagined possibility. This movement

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away from an event to an idea and then back again is almost exactly the same as the difficult operation of distanced simile or theory-constitutive analogy.

This post hoc description, however, goes little way towards explaining the difficulties of our students. For such a purpose we shall need to probe further and to examine, if at all possible, the mental processes and representations that they might need to use.

For Rumelhart and Norman (1981) there are several kinds of learning. In the simplest mode new facts are learnt by accretion to existing "declaratory" knowledge systems. They assume that the latter have little or no internal structure so that the facts can then be retrieved as simply as they were first loaded. Without a structure or a schema there can be no explaining of phenomena, so this mode of learning can only represent for us the students' acausal reaffirmation by use of synonym from a verbal meaning cluster or similar method.

Rumelhart and Norman categorise as "procedural" knowledge that which has been built up by experience. They show it to be contextually-bound, often tacit, and to form the basis of schemata which may be used to represent and interpret the phenomenon. They assert that new learning builds up new schemata by analogy with old. It is interesting that they also observe that learning through procedural knowledge is especially difficult because it is hard to identify the rules and representations within the system. It is immediately clear what implications this must have for the operation of theory-constitutive analogy where these internal representations need to become the rules of a new scientific explanation. It is little wonder that our science pupils find this method so difficult.

These authors also suggest that schemata borrowed from another context to interpret a new one will often need "tuning" for them to operate effectively in their new situation. The experiments the authors quote in this article then demonstrate the difficulties their own students had with such analogical operations.

The theory of mental models, as expounded by Johnson-Laird (1983) attempts to go even further and to understand the thinking processes themselves.

> "On the view developed here, to understand a phenomenon is to have a working model of it, albeit a model that may contain some simulated elements".

The "working model" is also described as "a structural analogue of the world" and hence may be just the kind of representation needed for scientific explanation. Despite an elaborate comparison with the recursive functions of a computor program, the author is emphatic that the recursive procedures of the mind, which map images and propositional representations into mental models, are themselves ineffable. What remains for examination are only the perceptual images,the propositions, and the final models. All the learning itself, which is the creation of mental models, thus depends upon unconscious processes.

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Fortunately the whole exploration does not quite chase itself down a blind alley. A mind may *not* study its own recursive processes and yet it *can* study the models that they have formed. This operation is introspection - a peculiarly human activity that even Turing machines are hard put to mimic, yet one that will be essential if the elements of one mental model are to be extracted for use elsewhere. For Johnson-Laird it is modelled by the difficulty of reprogramming parallel operating systems into serial ones which can be inspected and analysed. This, if Johnson-Laird's computer comparison holds, is the process which would be required for any conscious transfer of all or part of a mental model to another phenomenon by analogical thought. Unfortunately to describe our sophisticated method of scientific explanation by this functional analogy is only a very small step forward in thinking about its intrinsic difficulty, and hence about the problems of our learning children.

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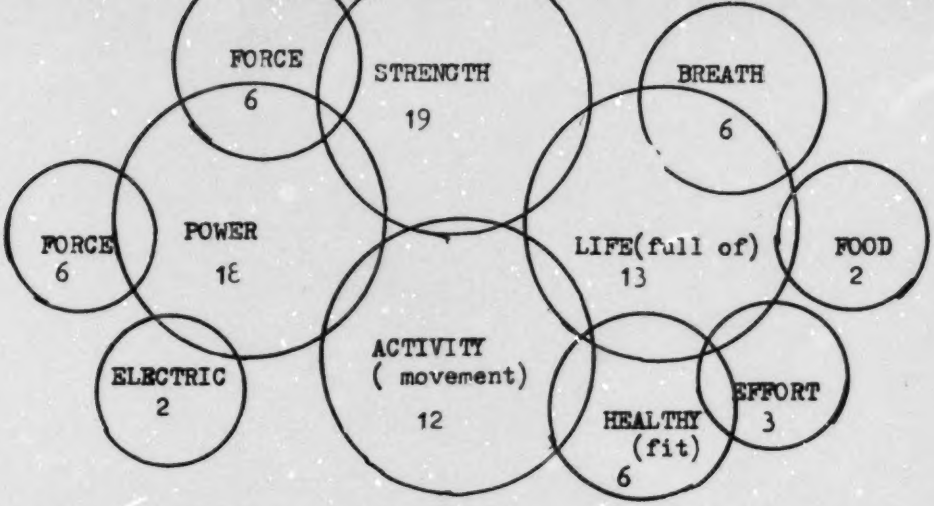

Figure 2

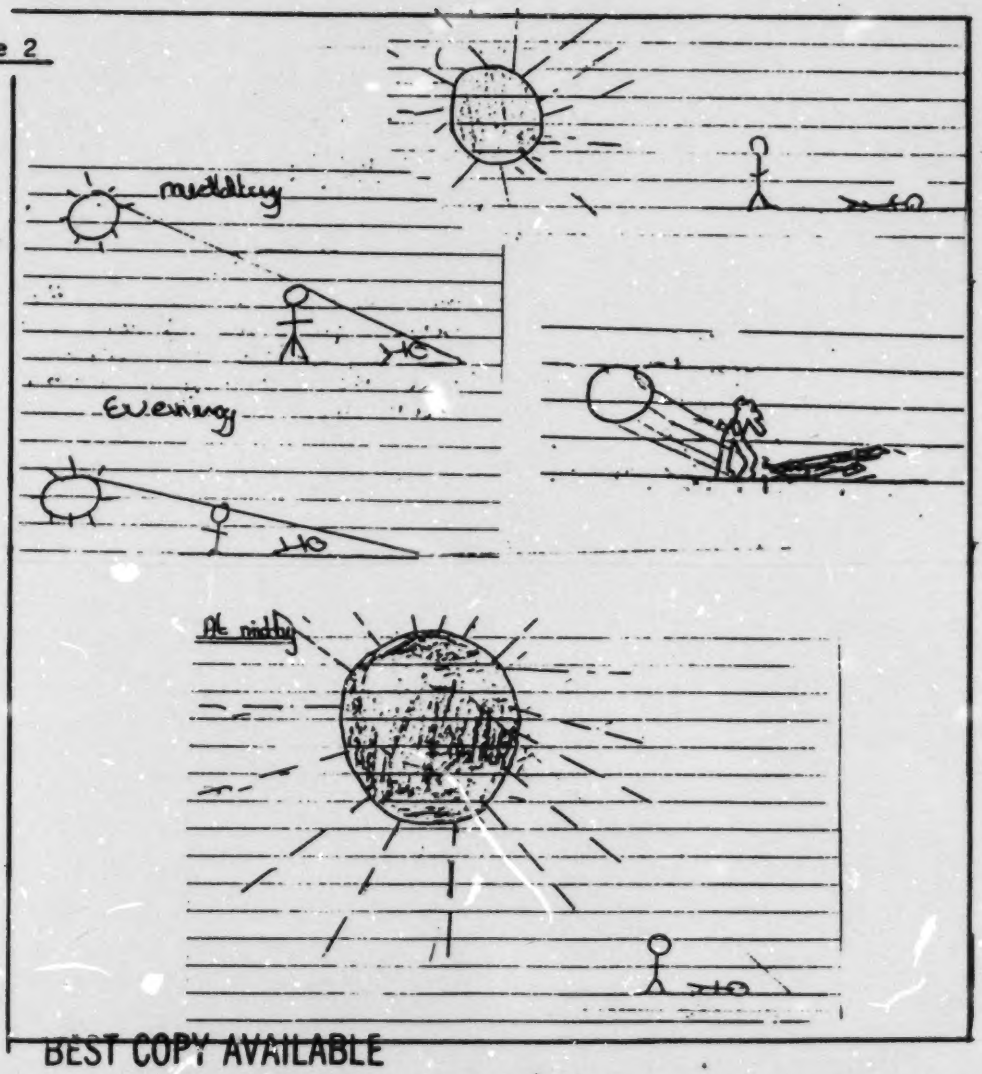

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Figure 3

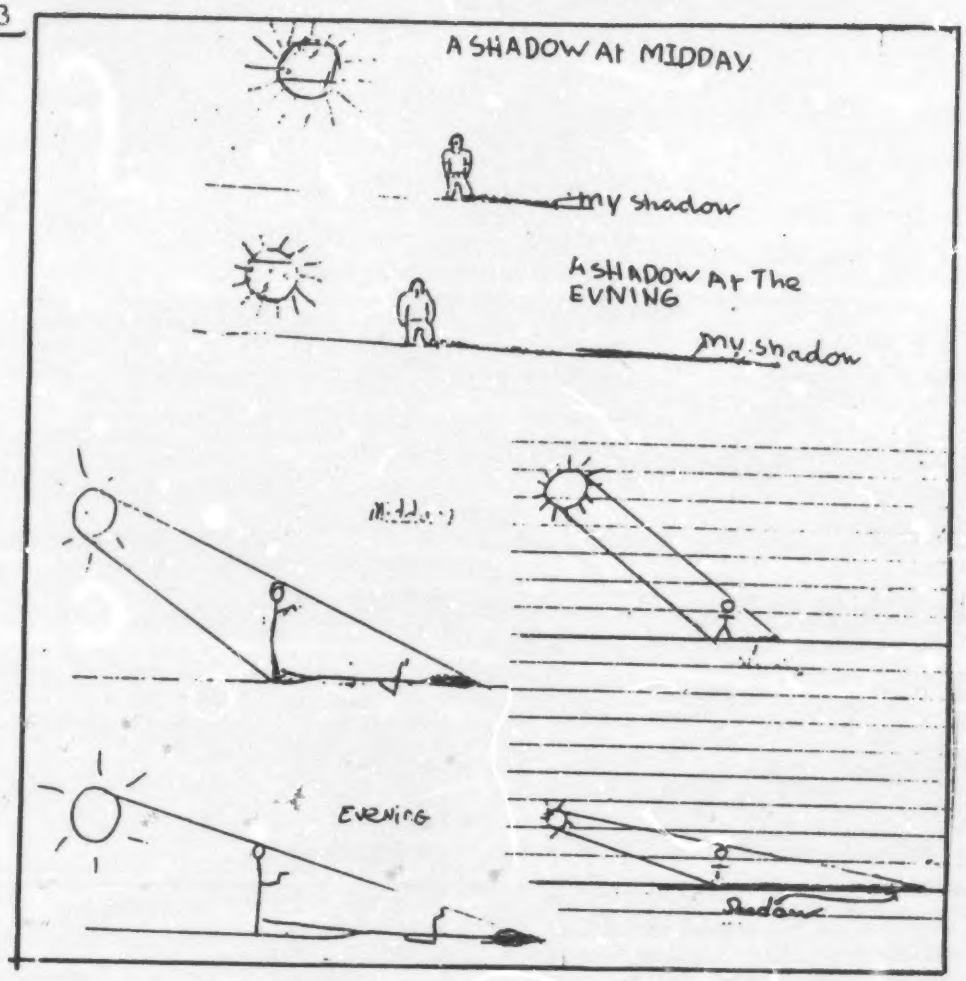

Table 1

PERCENTAGE SUCCESSES IN USE OF SIMILE

Distanced Similes			Comparison	Sample size
"Fire"	"River"	"Fuel"	"Dangerous animal"	n
73	76	73	92	120 (Grade 6)
82	84	75	95	125 (Grade 8)

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